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OPERATION JANGLE

TESTS OF SERVICE EQUIPMENT AND OPERATION

Project 6.3-1 Evaluation of Military Individual and Collective Protection Devices and Clothing (WT-401)

Project 6.3-2 Evaluation of Potential Respiratory Hazards Associated with Vehicular Operations in a Radioactively Contaminated Area (WT-402)

Project 6.7 Clothing Decontamination and Evaluation of Laundry Methods (WT-347)

Project 6.8 Evaluation of U.S. Army Field Water Supply Equipment and Operations (WT-340)

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OPERATION JANGLE

PROJECT 6.3-2

EVALUATION OF THE POTENTIAL RESPIRATORY HAZARD TO TANK CREWS REQUIRED TO OPERATE IN CONTAMINATED AREAS

by

ELMER H. ENGQUIST

July 1952



Chemical and Radiological Laboratories
Army Chemical Center, Maryland

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PREFACE

This report covers work conducted under Operation JANGLE Project 6.3, "Evaluation of Protective Equipment", John R. Hendrickson, Project Officer. The work at the test site was coordinated and conducted under the direction of the author.

The cooperation of many Chemical Corps individuals, too numerous to mention by name, assigned to the above projects contributed to the accomplishments of the objectives of this study. In addition, an Ordnance Test Team, directed by Captain David W. Armstrong and Mr. Norman Arnold, Ballistics Research Laboratories, Aberdeen Proving Ground, Maryland, and an Army Field Forces Board No. 2 Test Team, directed by Lt. Col. John S. Sandiland, provided the necessary support in the operation of the M26 tanks and the Personnel Carrier, T18E1. Each group provided many valuable suggestions and direction to the author. The assistance of Pfc John Sweeney was particularly valuable to the author in carrying out the installation of test apparatus and the tank collective protectors in the vehicles.

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ABSTRACT

The objective of this investigation was to assess the inhalation hazard to armored vehicles crews during the exposure to an underground and surface detonation of an atomic weapon and during operation, following the detonation, of the armored vehicles within the contaminated area resulting from fall-out.

Two types of armored vehicles were employed in this study, two Medium Tanks, M26, and one Personnel Carrier, T16E1, Pilot Model No. 5. During the surface shot only the two tanks were exposed 2000 ft in an upwind direction from ground zero and operated to within approximately one-tenth mile of ground zero. No contaminated area was traversed during this operation since the fall-out was restricted to a long narrow corridor in the downwind direction.

During the underground shot all three vehicles were exposed at 2000 ft in a downwind direction in an area contaminated to a level of approximately 550 roentgens/hr at H-hr + 1/2 hr. One tank was exposed head-on, with hatches open, one tank side-on with hatches closed, and the Personnel Carrier, head-on with the commander's and driver's hatches open. Following the shot at H-hr + 50 hr, after decontamination, the vehicles were operated with one tank leading with hatches open, and the other vehicles following with hatches closed, up to and beyond the crater lip and return.

During both exposure of the vehicles during the underground shot and operation through the contaminated area the airborne activity exceeded by a large degree the maximum allowable concentrations established by the Department of Defense and the U. S. Atomic Energy Commission for lifetime exposure. Preliminary to this operation a study was made to develop a basis for short-time exposure to airborne activity without exceeding the maximum allowable concentrations retained within the body. This study is appended to this report. The activity level measured exceeded the standards for eight hour exposure by a factor of 10 to 380.

There is thus a potential respiratory hazard during the initial 24 hour period to armored vehicle crews not wearing protective masks. The degree of this hazard cannot be firmly established due to the lack of definitive medical data on the result of this exposure. However, adequate protection can be provided to armored vehicle crews through the use of protective masks, and/or, tank collective protectors, and their use in similar situations is recommended.

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It is further recommended that results of this study be applied to the development of the overall hazard only after adequate consideration for the external dose to which personnel would simultaneously be exposed.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this investigation was to assess the inhalation hazard associated with (1) exposure of armored vehicles to an underground and surface detonation of atomic weapons, and (2) operation of armored vehicles through areas contaminated with fission products resulting from fall-out from such detonations.

1.2 AUTHORITY

The study on armored vehicles was conducted under Operation JANGLE Project 6.3, "Evaluation of Protective Equipment". The personnel carrier was included in accordance with 1st Indorsement, G4/F4/64171, dated 24 October 1951, from Office, AC/S, G4, Department of Army, to Chief Chemical Officer, D/A, on basic letter from Office, Chief of Army Field Forces, Fort Monroe, Virginia, subject: "Atomic Weapons Effects Testing".

1.3 HISTORICAL

Previous atomic weapons test, with the exception of Test Baker at Operation CROSSROADS were detonated as low air drops or detonated on towers. Thus, they were essentially of the non-contaminating type of burst since a major fraction of the fission product activity rose with the cloud and was diluted in the atmosphere. On 5 June 1950 the Joint Chiefs of Staff directed that underground and surface tests of nominal (20-30 kiloton) atomic weapons be conducted. As a result the Department of Defense through the Armed Forces Special Weapons Project established Operation WINDSTORM to be conducted on Amchitka in the Aleutian Islands. Subsequently, this operation was cancelled because of unfavorable test conditions of weather and terrain. The test were then rescheduled as Operation JANGLE for conduct with scaled atomic weapons, of approximately 1.25 kiloton yield, at the Nevada Proving Ground, U. S. Atomic Energy Commission, Mercury, Nevada. The surface test was detonated on 19 November 1951.

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1.4 THEORETICAL

The maximum permissible concentrations of radioactive isotopes in air have been established by the U. S. Atomic Energy Commission as standards for the control of radioactive materials in laboratories using such isotopes[1,2]. These concentrations are stipulated to constitute no hazard to personnel engaged in isotope work on a lifetime basis.

No standards are available for guidance of military operations in contaminated areas. It is a logical assumption that such operations are conducted with consideration of the hazards of such operations and acceptable risks will be taken where necessary for the accomplishment of the mission. Thus, such operations should only be conducted after assessment of the potential hazard and with adequate consideration of the risk. In military operations in contaminated areas it is expected that exposures will not be guided by standards established on the basis of lifetime exposure but rather on one-time, or at best a few, exposures to the hazard.

A study was made prior to Operation JANGLE to provide such a basis for military exposure. The calculations of Hunter and Ballou were used to furnish individual and total beta activities for fission products at various times between 1 hr and 1 yr after detonation. Then the concentration in air necessary to cause the deposition and retention of the maximum permissible amounts of Sr^{90} was calculated for several times after detonation, and for various exposure times. Each of the other fission products considered hazardous was then compared at several times to Sr^{90} on the basis of relative activity and toxicity. The possibility that "bad actors" might appear as decay products of active material already in the body was considered. Then estimates were made of their radio-toxicity relative to Sr^{90}. This relative value was called the "Sr^{90} equivalent". The concentrations necessary to cause retention of 1 Sr^{90} equivalent at various times were calculated and a graph prepared showing maximum permissible concentrations of fission products from 1 hr to 1 yr after detonation for various exposure times. This study results in the development of a much higher maximum permissible concentration than those set for long term exposure[3].

---

[1] Handbook of Atomic Weapons for Medical Officers, Prepared by Armed Forces Special Weapons Project, Department of Army Handbook 8-11, June 1951.

[2] Subcommittee on Internal Dose of the National Committee on Radiation Protection, "Maximum Permissible Concentrations of Radioisotopes in the Air, Water, and in the Human Body". (1951)

[3] CRLIR 64 "Maximum Allowable Concentration of Fission Products in the Air as a Function of Exposure Time and Time After Detonation".

[redacted]

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This study was further extended with modifications of the assumptions, refinement of the calculations, and consideration of the plutonium hazard. This study developed even higher concentrations than the initial study[4]. The reports are included as Appendices A and B.

[4]CRLIR 81 "Maximum Allowable Concentration of Fission Products in the Air as a Function of Exposure Time and Time After Detonation (Continued)".

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CHAPTER 2

EXPERIMENTAL

2.1 INSTRUMENTATION

To determine the airborne activity in the vehicles, and on the exterior of the vehicles, a Chemical Corps filter sampler was used. This device samples approximately one cfm of air through a 100 sq cm sheet of Chemical Corps Type 6 filter material backed up with two sheets of Chemical Corps Type 5 filter material for support. This unit is shown in Fig. 2.1. The units were operated for one hour starting at five minutes prior to the shot.

2.2 VEHICLES

2.2.1 M-26 Tank

The filter sampler was installed in the bow between the driver and assistant driver, in the turret ahead of the loader's seat, and on the outside fender of the tank. These installations are shown in Fig. 2.2, and Fig. 2.3.

2.2.2 Personnel Carrier T18E1

The filter sampler was located in the crew compartment only in this vehicle.

2.3 EXPOSURE POSITION OF VEHICLES

2.3.1 During Shot

During the surface shot the two medium tanks, M26, were located 2000 ft, 15° east of south, from ground zero. One tank was located head-on, and one side-on, to ground zero. This location was upwind of the area of contamination and little, if any, significant fall-out occurred at the location of the vehicles.

The principle evaluation for the purposes of this report was conducted on the underground shot. The three vehicles were located at 2000 ft from ground zero in the fall-out direction. This area was contaminat

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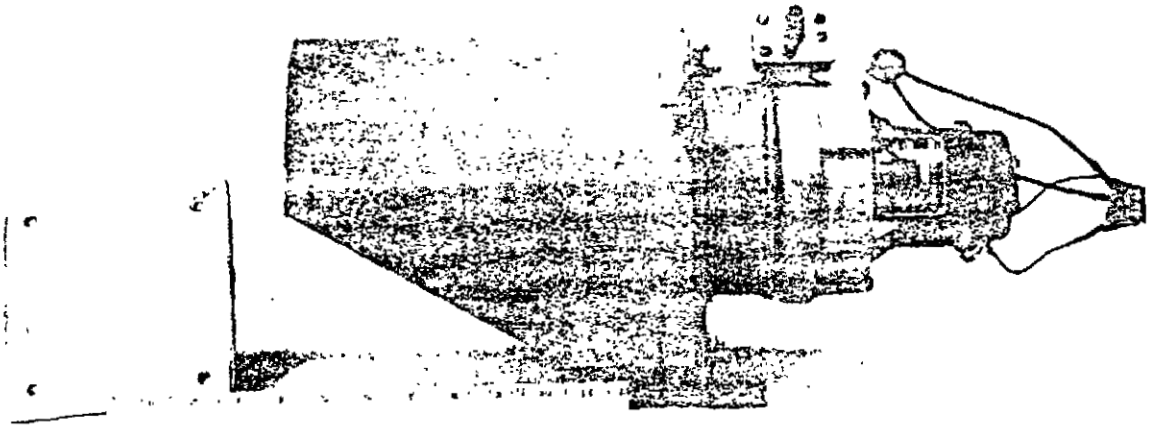


Fig. 2.1 Chemical Corps Filter Sampler

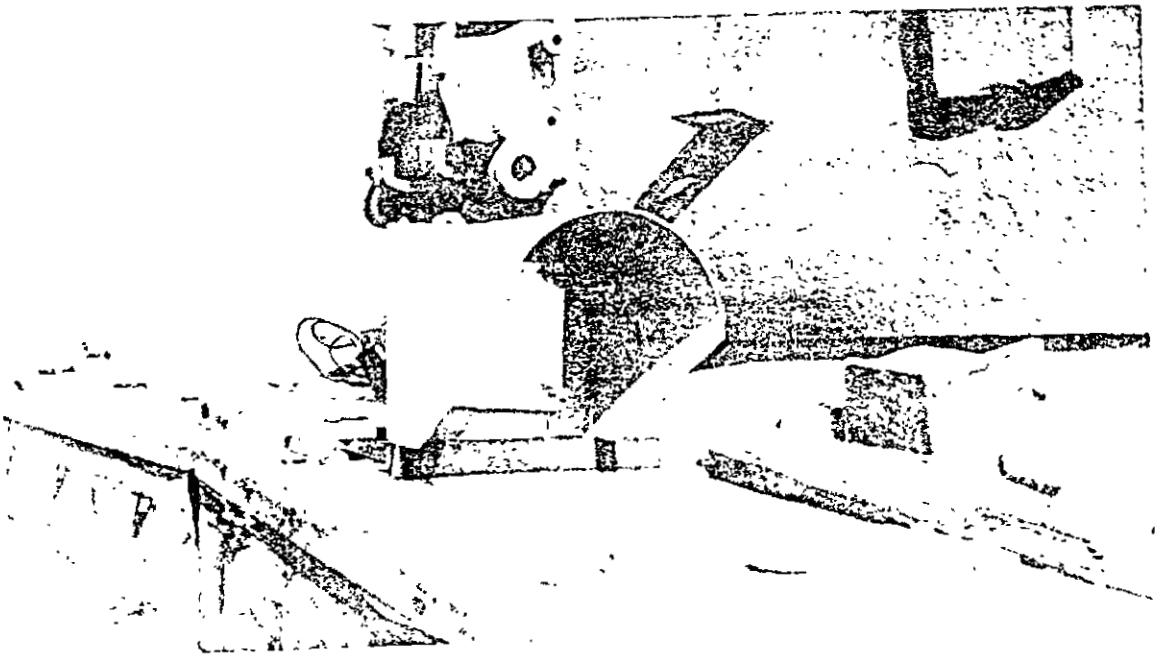


Fig. 2.2 Chemical Corps Filter Sampler Installations on M26 Tanks

to a level of 550 roentgens/hr at H-hr + 1/2 hr. One tank was located head-on, one tank side-on, and the Personnel Carrier, T18E1, Pilot Model No. 5, was located head-on to ground zero. The hatches were open on the head-on tank, closed on the side-on tank and the commander's and driver's hatches open on the Personnel Carrier, T18E1.

2.3.2 Areas of Operation Following Shots

The routes of operation of the vehicles through the contaminated area created by the two shots are shown in Fig. 2.4. The route shown for the surface shot was traversed at H-hr + 25 hrs, and the route shown for the underground shot was traversed at H-hr + 50 hrs. On the underground shot, the M-26 Tank 424-S was the lead vehicle, hatches open, followed by the M-26 tank 418-S and the Personnel Carrier, T18E1, hatches closed.

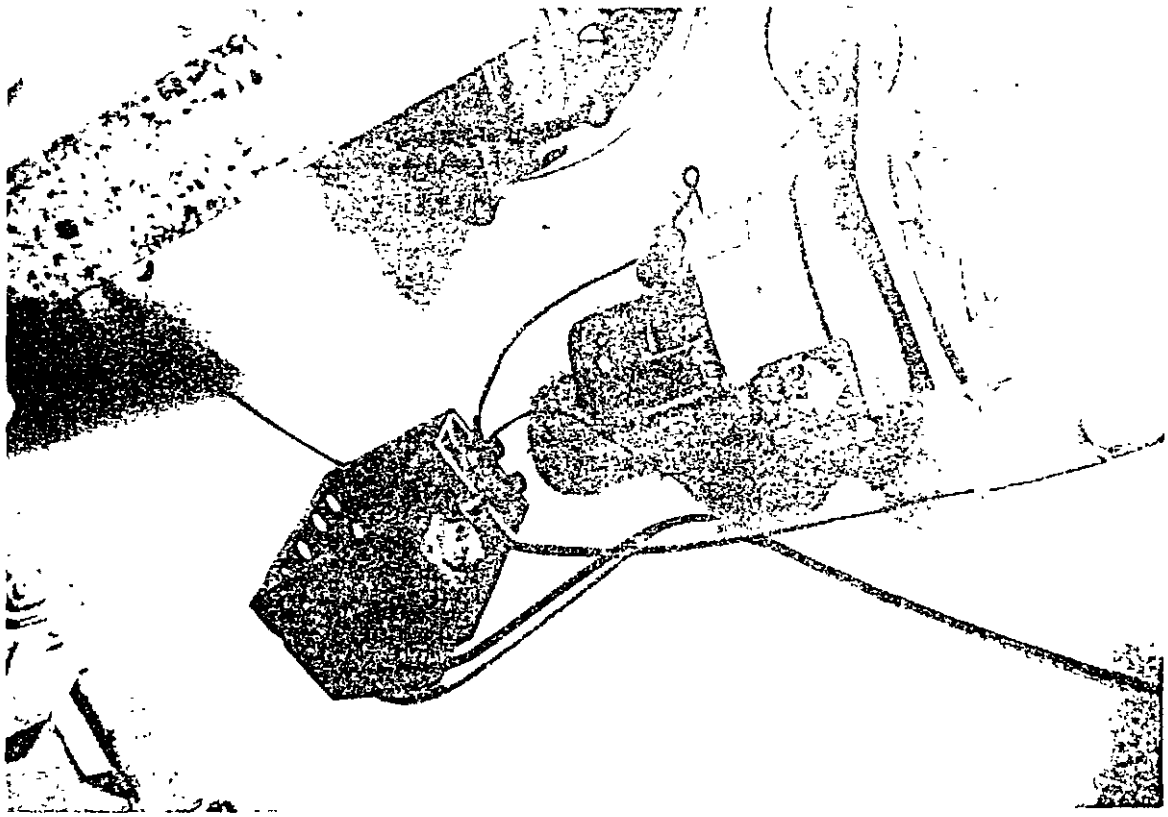
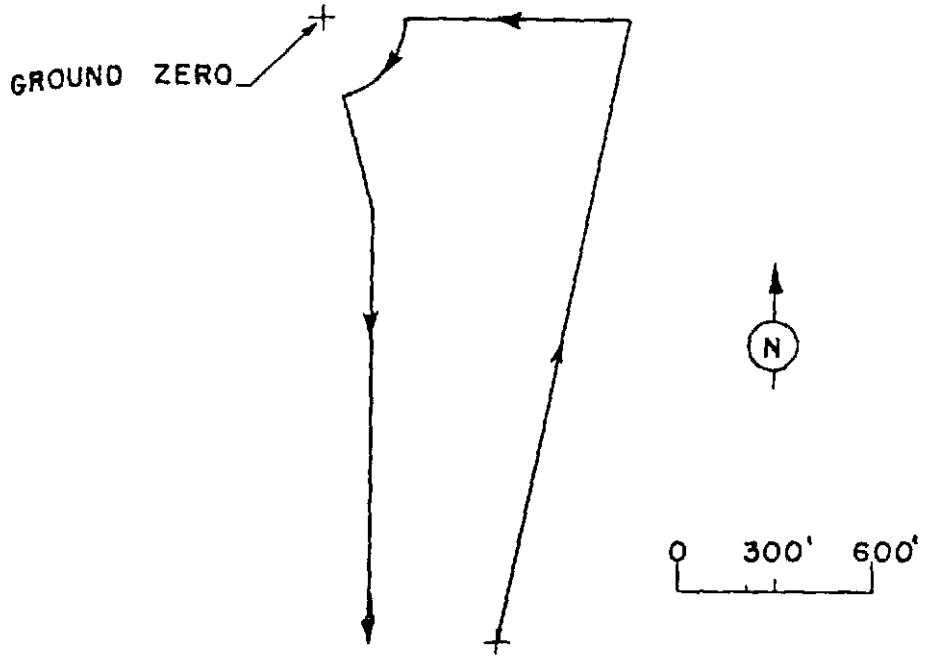


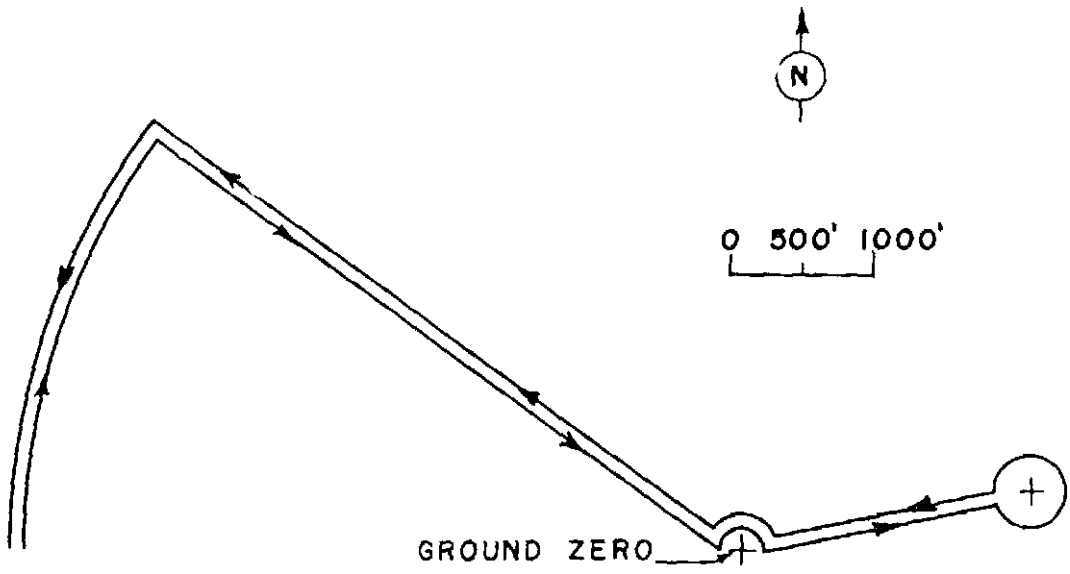
Fig. 2.3 Chemical Corps Filter Sampler Installation in M26 Tank

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TANK ROUTE FOLLOWING SURFACE DETONATION



ARMORED VEHICLE ROUTE FOLLOWING UNDERGROUND DETONATION

Fig. 2.4 Areas of Operation of Vehicles in Contaminated Areas

[redacted]

CHAPTER 3

RESULTS

3.1 AIRBORNE ACTIVITY LEVEL IN VEHICLES DURING UNDERGROUND SHOT

The data on airborne beta activity level in vehicles are given in Table 3.1. The samples were taken for 55 minutes following the shot and the counting data were arbitrarily corrected to H-hr + 1 hr by means of the decay equation for gross fission products, $A = A_0 t^{-n}$, where the decay exponent was taken as 1.48. This was the experimentally determined value on the samples. Activity levels collected by the samples varied randomly with location within the vehicles from 0.17 to 0.45 millicuries per liter of air. The following averaged concentrations were obtained for the three vehicles:

Vehicle	Millicuries/Liter
M26 Tank - Hatches Closed	0.23
M26 Tank - Hatches Open	0.27
T18E1 Personnel Carrier	0.28

3.2 AIRBORNE ACTIVITY LEVEL IN VEHICLES DURING TEST RUN FOLLOWING THE UNDERGROUND SHOT

The data shown in Table 3.2 were obtained during the test run following the underground shot through the contaminated area to the crater lip and beyond, and return, as shown in Fig. 2.3.

TABLE 3.1

Airborne Activity Level In Armored Vehicles

Vehicle	Location	Activity (mc)	Sampling Time (min)	Sampling Volume (l/min)	Activity/Liter (mc/liter)
M-26 Tank 424-S	Turret	12.2	60	1.23	0.17
M-26 Tank 424-S	Hull	21.2	60	1.08	0.33
M-26 Tank 424-S	Outside	11.0	60	0.95	0.19
Average Concentration					0.23
M-26 Tank 418-S*	Turret	30.6	60	1.12	0.45
M-26 Tank 418-S*	Hull	13.0	60	1.23	0.18
M-26 Tank 418-S*	Outside	14.0	60	1.28	0.18
Average Concentration					0.27
Personnel Carrier T18E1	Personnel Comp't	19.4	60	1.15	0.28

*Hatches Open

SECRET

RESTRICTED DATA

TABLE 3.2

Airborne Activity Level During Armored Vehicle Test Run*

Vehicle	Location	Activity (mc)	Sampling Time (min)	Sampling Volume (l/min)	Activity/Liter (mc/liter)
M-26 Tank 418-S	Turret	2.63	23	1.12	0.102
M-26 Tank 418-S	Hull	1.0	23	1.23	0.035
M-26 Tank 418-S	Outside	0.12	23	1.28	0.004
Average Concentration					0.068
M-26 Tank 424-S	Turret	0.48	23	1.23	0.017
M-26 Tank 424-S	Hull	9.0	23	1.08	0.362
M-26 Tank 424-S	Outside	1.2	23	0.95	0.055
Average Concentration					0.18
Personnel Carrier T18E1	Personnel Comp't	1.0	23	1.15	0.038

*M-26 Tank 424-S was the lead vehicle, hatches open, followed by the M-26 Tank 418-S, and the Personnel Carrier, T18E1, hatches closed.

[redacted]

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CHAPTER 4

DISCUSSION

4.1 VARIATION OF AIRBORNE ACTIVITY

It is considered significant that the airborne activity does not appear to vary markedly with the operational condition of the tanks; that is, whether the vehicle hatches are open or closed during the period of exposure. This is clearly indicated by the data given in Section 3.1. It was further indicated immediately after removal of the sampling papers from the test samplers when the papers were monitored by survey meters at H-hr + 70 hrs before shipment to the Army Chemical Center for detailed analysis. The measured activity on the papers at that time varied from 7 to 35 mr/hr at 6 in. from the samples.

During the test run through the contaminated area following the underground shot it is to be noted that there was no significant difference in activity in the lead vehicle as opposed to the two following "buttoned-up" vehicles, with ventilating system operating. This is strong indication that the major portion of the airborne material within the vehicle was a secondary aerosol created from contamination within the vehicle itself.

4.2 FACTORS AFFECTING APPLICATION OF DATA

Before applying the results of this investigation to an assessment of inhalation hazard associated with airborne radioactive material to armored vehicle personnel three additional factors should be considered. First it should be emphasized that no effort was made to limit the spectrum of particle size sampled by the filter samplers to that which is in the specific size range for lung retention. The particle size for retention has an upper limit of 10 microns, and more probably 3 microns. Data developed by Operation JANGLE Project 2.5a, Airborne Cloud Studies, indicate that less than 10 per cent of the total airborne activity is in the inhalation hazard size range of 0.5 to 5.0 microns[5].

Second, the protective measures available to personnel must be considered. The gas mask, or more specifically for armored vehicle crews,

[5]Letter to, Office of the Director, Effects Test, c/o Technical Operations Squadron (Prov), Washington 13, D.C., from CO, Cml C Chemical and Radiological Laboratories, Army Chemical Center, Md., dated 18 April 1952.

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the Tank Collective Protector, E26, has an extremely high efficiency for the removal of gross fission product contaminant associated with the cloud and base surge created by an underground detonation[6]. The average penetration of these units by radioactive particles was measured at 0.018 per cent, that is, 1.8 parts in 10,000 pass through the tank collective protector filter unit.

Third, the time of exposure must be considered. For short-term exposure, if one accepts the assumptions as outlined in Appendices A and B which provide the basis for calculation of short-term exposure to gross fission products, 8 hr exposure to 0.1 to 0.0035 microcuries per liter of gross fission products can be tolerated during the period of H + 1 hr to H + 1 day. This time of exposure was the shortest considered in the analysis and, since tank crews generally could be expected to be exposed for even shorter periods than 8 hrs during operations within contaminated areas, they could tolerate slightly higher levels of airborne contamination.

4.3 FACTORS BY WHICH MEASURED AIRBORNE CONCENTRATION EXCEED MAXIMUM ALLOWABLE CONCENTRATIONS

The concentrations given in Table 3.1 and 3.2, allowing for the 10 per cent size range factor, exceed the maximum allowable concentrations given in Appendices A and B, as given in Table 4.1.

TABLE 4.1

Factors by which Measured Airborne Concentration Exceed Maximum Allowable Concentrations

Time of Exposure	Maximum Allowable Concentration µc/l (for 8 hr Exposure)[1]	Measured Concentration		Factor by which Measured value exceeds Max. Allowable Conc.	
		Maximum µc/l	Minimum µc/l	Maximum	Minimum
H + 24 hr	0.0035	0.252	0.034	72	10
H + 1 hr	0.1	28.	3.8	280	38

[1] Appendices A and B

[6] "Evaluation of Protective Equipment", Operation Jangle Project 6.3, John R. Hendrickson, Army Chemical Center, Maryland.

6.4 EVALUATION OF THE POTENTIAL HAZARD

Thus, unprotected personnel would be exposed to concentrations exceeding the maximum allowable concentration for 8 hr exposure by a factor of 10 to 280, and there is thus a requirement for tank personnel to wear protective masks when operating within contaminated areas. Such protective masks would probably be worn for comfort purposes under any conditions, if available, under dusty conditions such as were encountered at the Nevada Proving Ground.

Wearing protective masks, with a penetration of 2 parts in 10,000, and considering that 10 per cent of the activity is in the respiratory size range, the concentrations inhaled are well below the maximum allowable concentration for eight hour exposure as outlined in Appendices A and B. There thus appears to be little hazard to tank crews wearing protective masks.

Without more definitive respiratory retention data, and the results of such exposure, it is not possible to determine the magnitude of the hazard to unprotected personnel. By comparison of the measured activity levels with U. S. Atomic Energy Commission and military standards for maximum permissible concentrations of radioactive isotopes in the air for lifetime exposures (which offer substantial safety factors), and by comparison with the short-term exposure limits for negligible hazard, there is an exposure problem to avoid all hazard. However, the degree of the hazard present in exposure which exceeds the maximum allowable concentrations has not been established to date and therefore the magnitude of the exposure to unprotected tank personnel cannot be firmly established.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. Based on the data developed by this study there is a potential respiratory hazard during the initial 24 hr period to armored vehicle crews not wearing protective masks from the airborne fission product activity associated with the base surge and during the operation of armored vehicles through contaminated areas.

2. Satisfactory respiratory protection can be provided to armored vehicle crews operating in contaminated areas through the use of protective masks, and/or, tank collective protectors.

5.2 RECOMMENDATIONS

1. In developing the overall personnel hazard it is recommended that the results of these studies be applied only after adequate consideration for the external dose to which personnel would also be exposed.

2. It is recommended that protective masks, and/or tank collective protectors, be used in situations similar to that presented by the Operation JANGLE tests.

3. It is recommended that these data be extrapolated to the condition encountered during detonations of nominal or operational atomic weapons.

[redacted]

PROJECT 6.3-2

APPENDIX A

MAXIMUM ALLOWABLE CONCENTRATIONS OF FISSION PRODUCTS IN THE AIR AS A FUNCTION OF EXPOSURE TIME AND TIME AFTER DETONATION

and

APPENDIX B

MAXIMUM ALLOWABLE CONCENTRATIONS OF FISSION PRODUCTS IN THE AIR AS A FUNCTION OF EXPOSURE TIME AND TIME AFTER DETONATION
(Continued)

by

ROBERT L. HARVEY
Lt, U. S. Navy

Radiological Division
Chemical Corps
Chemical and Radiological Laboratories
Army Chemical Center, Maryland

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PROJECT 6.3-2

APPENDIX A

MAXIMUM ALLOWABLE CONCENTRATIONS OF FISSION PRODUCTS IN THE AIR AS A FUNCTION OF EXPOSURE TIME AND TIME AFTER DETONATION

A.1 INTRODUCTION

During the planning of a decontamination project at the Radiological Division, Chemical and Radiological Laboratory, Army Chemical Center, Md., it was observed that the procedures to be employed might cause the formation of secondary aerosols, and that these might well pose an internal health hazard. Provision was then made to make beta activity determinations in microcuries per liter of air in the vicinity of the exposed personnel. It was then observed that the determination would be of little value unless there were some criterion for determining whether or not the measured activity were actually an hazard. Unfortunately, the figures in the literature, some of which were listed in Table A.1, were all set for steady state conditions, that is to say, for continual exposures for long periods of time. These figures it was felt might well be unrealistic for short-term exposures, that is to say, that permissible concentrations might be higher.

A.2 OBJECTIVE

It was decided that to be of genuine utility to the military a graph would have to be prepared with maximum permissible fission product concentration in microcuries per liter of air as the ordinate and time after detonation of an atomic bomb as the abscissa, showing a family of curves corresponding to given lengths of exposure time.

A.3 METHOD OF ATTACK

It was first assumed that the activities resulting from the slow-neutron fission of U^{235}, as reported by Hunter and Ballou (6), were close enough to those arising from fast fission to serve as a guide for the contributions of the nuclides under consideration. Then the further assumption was made that any airborne fission product mixture would have the same composition.

Sr^{90} was selected as the base, or reference activity since it is the most persistent, though not the most serious hazard (1), (3), (4), (5), (7), (8), after having been metabolized into the human body. Not only that, but during the period of time under consideration, its activity could be

[redacted]

TABLE A.1

Maximum Permissible Concentrations of Various Elements in the Atmosphere for Continual Exposure

Element	β-ν Act. in μc/l	El.	α Act. in μc/l	Ref.	Remarks
I, Sr, Ba	10^{-4}	Pu	3×10^{-8}	1	Alpha exposure for an 8-hr day, 6-day week for 1 yr
Fission Product	2×10^{-7}	Pu	1.5×10^{-9}	2	Continual exposure
I, Sr, Ba	10^{-4}	Pu	3×10^{-8}	3 p.26	Alpha exposure for an 8-hr day, 6-day week for 1 yr
Long-lived beta-gamma emitter	10^{-5}	(Pu) α	3×10^{-8}	3 p.86	- - - - - - -
I	3×10^{-6}	Pu	2×10^{-9}	4 p.71	Continual exposure
Beta or gamma emitter	10^{-6}	Pu	2×10^{-9}	5	Continual exposure

considered constant. Now it is known that the standard man breathes 10 cu.m. of air during an 8-hr working period, and a total of 20 cu.m. of air during a 24-hr period which includes an 8-hr working period (8). The maximum permissible amount of Sr^{90} in the human body is 1 microcurie (4). If the assumption is then made that 25 per cent of the airborne Sr^{90} which is breathed in (4), (5) is retained permanently, the maximum permissible amounts of this nuclide in the atmosphere may be calculated. Twenty-five per cent retention, of course, is too high an estimate by a factor of four, as reported by ICRP (4), and neglects biological decay.

The calculation is as follows:

Let Y = the number of liters of air breathed in during the time in question, and

Z = maximum permissible amount of Sr^{90} retained in the body (1 microcurie), then to determine



X = maximum permissible concentration of Sr^{90} in microcuries per liter of air breathed during the time in question

Formula A.1

$$Z = (XI) \times .25$$

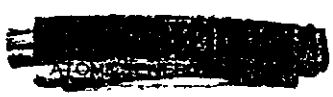
Table A.2 shows several values of X.

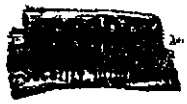
TABLE A.2

Concentration of Sr^{90} in air necessary to cause retention in the human body of 1 microvurie (or 2 microcuries of Sr^{90}-Y^{90}, since they are parent and daughter in stable equilibrium) during the following periods of time, based on the absorption and permanent retention of 25 per cent of the activity.

Time of Exposure	Concentration μc/liter
8-hr work day	4×10^{-4}
24-hr including an 8-hr work day	2×10^{-4}
7 days including an 8-hr work day each day	2.8×10^{-5}

Now having evaluated the maximum permissible concentrations of Sr^{90} in the air for several exposure times, the gross fission product activity required to provide such concentrations was calculated (see the sample calculation at the bottom of Table A.3). The figures in Table A.3 were plotted on Figs. A.1 and A.2. Thus looking at Figs. A.1 and A.2, we can enter the graph at any time, from 1 hr to 1 yr after detonation, and find the gross fission product activity which, if the assumptions be sound, will cause the deposition and retention of no more than 1 μc of the Sr^{90} in the body. For example, if it is desired to enter a contaminated area 10 hrs after detonation and to stay for 8-hrs, take the abscissa as 10 + 8 hrs, or 18-hrs, run a vertical line up to the 8-hr line, and from the point of intersection, read the maximum permissible concentration, at the left margin, of 34 μc/l. Eighteen hours was used as the entry figure, since the total beta activity decays appreciably during the period, but the Sr^{90} activity does not. It is further noted that although the curves in Fig. A.2 tail downwind, it is expected that they will level off (see p. 73 of ref. 6) toward a partial asymptote.





It is plain, however, that Sr^{90} is not the only hazardous fission product. Hamilton (7) indicates that several members of the rare earth group are indeed deserving of consideration. Those considered significant are listed in Table A.4. Each of these nuclides was evaluated as having associated hazards which were so many multiples of Sr^{90}, on the basis of equal activities - than that associated with Sr^{90}.

To arrive at these relative values the following factors were considered: (a) maximum permissible concentration of each nuclide in the body (5) (see second column, Table A.4) and (b) relative activities at various times. The ratios of the various significant fission product activities were roughly estimated by the author by using Hunter and Ballou's plots of activity (6). It then followed that at a given time so many equivalent Sr^{90} activities existed in the presence of 1 unit of actual Sr^{90} activity. Therefore the gross fission product activities listed in Table A.3 were divided by the total Sr^{90} equivalents existing at each time, and the results were plotted in Figs. A.3 and A.4. Thus, a plot of the maximum permissible gross fission product activity vs. time after detonation for various times of exposure was achieved. It is well to emphasize that according to the assumptions drawn here, the maximum deposition and retention is 1 μc of equivalent Sr^{90} activity.

A.5 DISCUSSION

It is recognized that this whole report is largely qualitative in nature and is therefore subject to modification. Several of the questionable aspects of this report will be discussed here by way of amplification.

For simplification the activity of Sr^{90} was considered constant. This is essentially so during the period in question (6). The assumption that 25 per cent of all material inhaled is absorbed and retained permanently, as previously observed, was a high estimate and presents the worst possible picture (4,5,7). In addition particle size distribution has not been considered at all, nor has the accumulation of material in the lungs. Thus it is highly questionable whether the body will have an equivalent of 1 μc of Sr^{90} activity at any time under the stated conditions.

It will be noted further that the assumptions regarding Sr^{90} have been applied to all the other elements considered in Table A.4. The Sr^{90} equivalents - or weighting factors - for each nuclide were arrived at by considering their maximum permissible concentration in the body, their relative activity to that of Sr^{90} at given times.

Iodine was included as the only nonbone seeker, inasmuch as it was determined that a hazard would develop in the thyroid before it existed in the bone, because of rapidity of uptake (the hazard to the rest of the body

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PROJECT 6.3-2

TABLE A.3

Maximum Permissible Fission Product Concentration

Time after detonation	Sr^{90} Act. as % of total beta activity(a)	Gross fission product beta activity in μc/l required to cause retention of 1 μc of Sr^{90} in the human body during the following exposure times		
(6)	(6)	8-hr. work day	24-hr(b)	7 days(b)
1 hr	4.35×10^{-5}	920.	460.	66.
3.5 hr	1.82×10^{-4}	220.	110.	16.
12 hr	7.11×10^{-4}	0.56	0.28	3.9
24 hr	1.55×10^{-3}	26.	13.0	1.8
2 days	3.50×10^{-3}	11.5	5.65	0.81
4 days	8.0×10^{-3}	5.0	2.6	0.37
7 days	1.5×10^{-2}	2.7	1.35	0.2
14 days	3.2×10^{-2}	1.25	0.63	0.099
28 days	7.7×10^{-2}	0.52	0.26	0.04
105 days	2.86×10^{-1}	0.14	0.07	0.01
210 days	7.3×10^{-1}	0.055	0.028	0.004
1 yr	1.96	0.020	0.01	0.001

(a) These figures were adjusted slightly to give smooth curves.

(b) Each 24-hr period includes an 8-hr working period.

SAMPLE CALCULATION

At 1 hr Hunter and Ballou (6) give the Sr^{90} activity as 4.35×10^{-5} per cent of the total beta activity. From Table A.2 the concentration of Sr^{90} in the air necessary to cause the deposition and retention of 1 μc at the end of an 8-hr work day is 4×10^{-4} μc/l. Therefore:

$$\frac{4 \times 10^{-4}}{4.35 \times 10^{-5}} \times 100 = 920 \text{ μc/l}$$

[redacted]

[redacted]

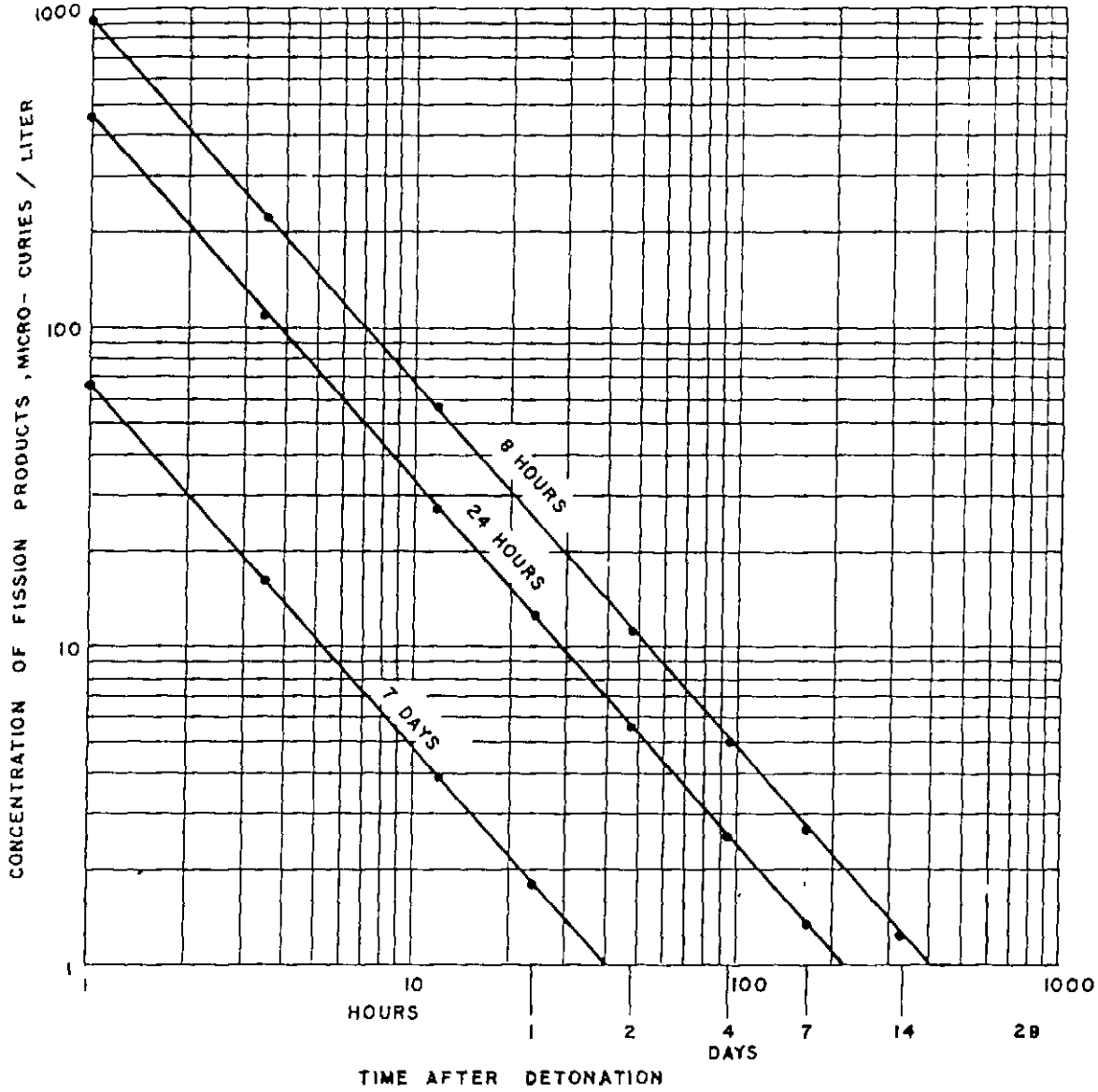


Fig. A.1 Maximum Permissible Concentrations of Fission Products in the Air - 1 hr to 1000 hr (So that not more than 1 micro-curie of Sr^{90} is retained in the body)

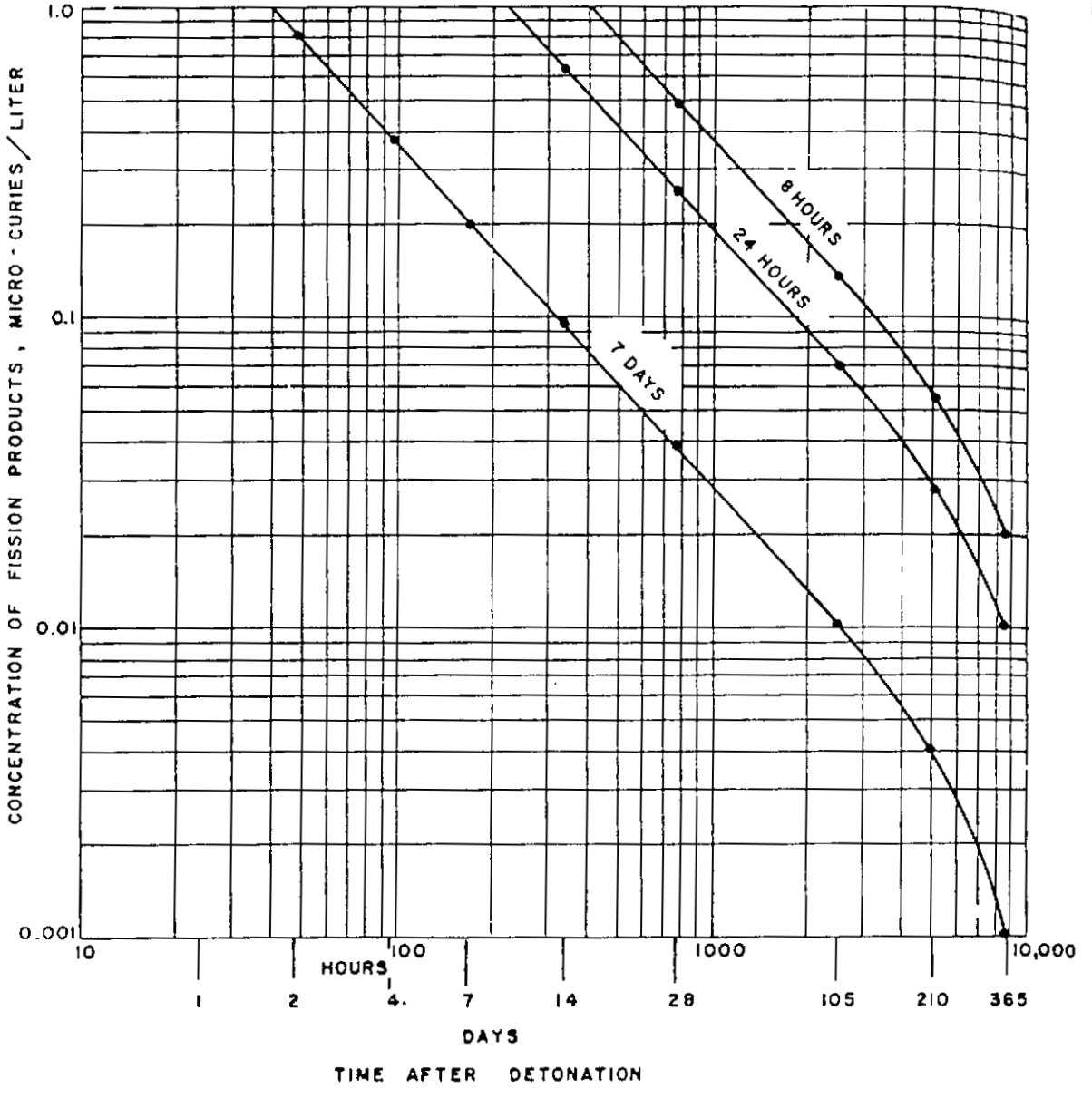


Fig. A.2 Maximum Permissible Concentrations of Fission Products in the Air - 10 hr to 1 yr (So that not more than 1 microcurie of Sr^{90} is retained in the body)

DECLASSIFIED DATA
ATOMIC ENERGY

TABLE A.4

Analysis Sheet

Listed below are those fission products which constitute internal hazard. Their beta activities and Sr equivalents are given for various times.

1	2	3		4		5		6		7		8	
Nuclide	Maximum Permissible Concentration in the body in microcuries	1 hr		12 hr		24 hr		1-10 days(d)		10-100 days(d)		100-1000 days(d)	
		Per cent of total activity	Sr^{90} equivalents	Per cent of total activity	Sr^{90} equivalents	Per cent of total activity	Sr^{90} equivalents	Per cent of total activity	Sr^{90} equivalents	Per cent of total activity	Sr^{90} equivalents	Per cent of total activity	Sr^{90} equivalents
(7)	(5)	(6)		(6)		(6)		(6)		(6)		(6)	
I^{131} (a)	0.3	0.02	1530	0.4	1880	1.	2150	3.	1000	3.	67	0	0
Sr^{90}-Y^{90} (b,f)	2.0	4.35×10^{-5}	2	7.4×10^{-4}	2	1.55×10^{-3}	2	0.01	2	0.15	2	8.0	2
Sr^{89} (b)	2.0	0.006	140	0.1	140	0.24	150	2.	200	7.	47	2.5	0.31
Ba^{140}-La^{140} (b)	5.8	0.037	150	0.66	160	1.73	110	10.	175	16.	8	0	0
Y^{91} (c)	0.3	0.17	13000	2.9	13600	3.00	645	2.	670	6.5	145	3.0	1.25
Zr^{95}-Cb^{95} (c)	0.3	0.006	460	0.12	560	0.26	560	2.	670	16.	360	16.0	6.7
Ce^{144}-Pr^{144} (c)	0.3	0.0024	185	0.04	190	0.51	240	0.7	240	7.	155	50.0	21.0
Ce^{143}-Pr^{143} (c)	0.3	0.27	20700	4.4	20600	8.6	18500	16.5	5500	7.	155	0	0
Nd^{147}-Pr^{147} (c)	0.3	0.8	13800	2.7	12700	6.3	12200	3.5	1170	3.	67	10.0	4.2
Total Sr^{90} equivalents			48437		47952		32407		8627		939		35.46
Equivalents used in figures A.3 and A.4			5×10^5		5×10^5		3.5×10^5		9×10^4		1×10^4		3.6×10^2

(a) The figures given under the columns "Sr^{90} equivalents" for I^{131} indicate only the multiples of maximum permissible iodine activity present when the maximum permissible concentration of Sr^{90} is present (8).

(b) Metabolism of this nuclide is similar to that of Radium (7).

(c) Metabolism of this nuclide is similar to that of Plutonium (7) (8).

(d) Estimated mean beta activity (6).

(e) Figures in column 2 for Sr^{90} -Y^{90}, Ba^{140}-La^{140}, Zr^{95}-Cb^{95}, and Ce^{144}-Pr^{144} etc. are based on the assumption that the maximum permissible concentration in the body for a parent-daughter pair is equal to the maximum permissible concentration of the parent. The per cent of total activity figures in columns 3 through 8 represent the sum of the activities of the parent and daughter.

(f) Y^{90} activity grows into equilibrium with Sr^{90} between 1-10 days. Prior to 1 day Sr^{90} is predominant.

(g) The figures in columns 6, 7, and 8 were arrived by estimating a mean value of the activity for each nuclide during the period in question using Hunter and Ballou's figures (6). The total Sr^{90} equivalents were therefore multiplied by 10 to provide a factor of safety should an entry be made in figures A.3 and A.4 on the high side of the means.

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PROJECT 6.3-2

TABLE A.5

Maximum Permissible Fission Product Concentrations

Time after detonation	Sr^{90} Equivalents(a)	Gross fission product beta activity in μc/l required to cause retention of 1 Sr^{90} equivalent in the body during the following exposure times(b)		
		8-hr work day	24-hr (c)	7 days (c)
1 hr	5×10^{5}	1.84×10^{-3}	9.2×10^{-4}	1.31×10^{-4}
3.5 hr	5.5×10^{5}	4.0×10^{-4}	2.0×10^{-4}	2.86×10^{-5}
12 hr	4.65×10^{5}	1.2×10^{-4}	6×10^{-5}	8.6×10^{-6}
24 hr	3.24×10^{5}	8.0×10^{-5}	4×10^{-5}	5.7×10^{-6}
2 days	1.8×10^{5}	6.4×10^{-5}	3.2×10^{-5}	4.6×10^{-6}
4 days	9×10^{4}	5.5×10^{-5}	2.75×10^{-5}	3.93×10^{-6}
7 days	5.6×10^{4}	5.3×10^{-5}	2.65×10^{-5}	3.78×10^{-6}
14 days	2.4×10^{4}	5.2×10^{-5}	2.60×10^{-5}	3.72×10^{-6}
28 days	1×10^{4}	5.2×10^{-5}	2.6×10^{-5}	3.72×10^{-6}
105 days	2.7×10^{3}	5.3×10^{-5}	2.65×10^{-5}	3.78×10^{-6}
210 days	9.65×10^{2}	5.4×10^{-5}	2.7×10^{-5}	3.86×10^{-6}
1 yr	3.6×10^{2}	5.6×10^{-5}	2.8×10^{-5}	4.0×10^{-6}

(a) These figures were taken from the last row of figures on Table A.4 and were adjusted to give a smooth set of curves.

(b) The figures in these three columns were determined by dividing the figures in the corresponding columns of Table A.3 by the respective numbers of Sr^{90} equivalents (the last row of figures in Table A.4). The quotients were plotted and adjusted to give a smooth curve.

(c) Indludes an 8-hr work day.

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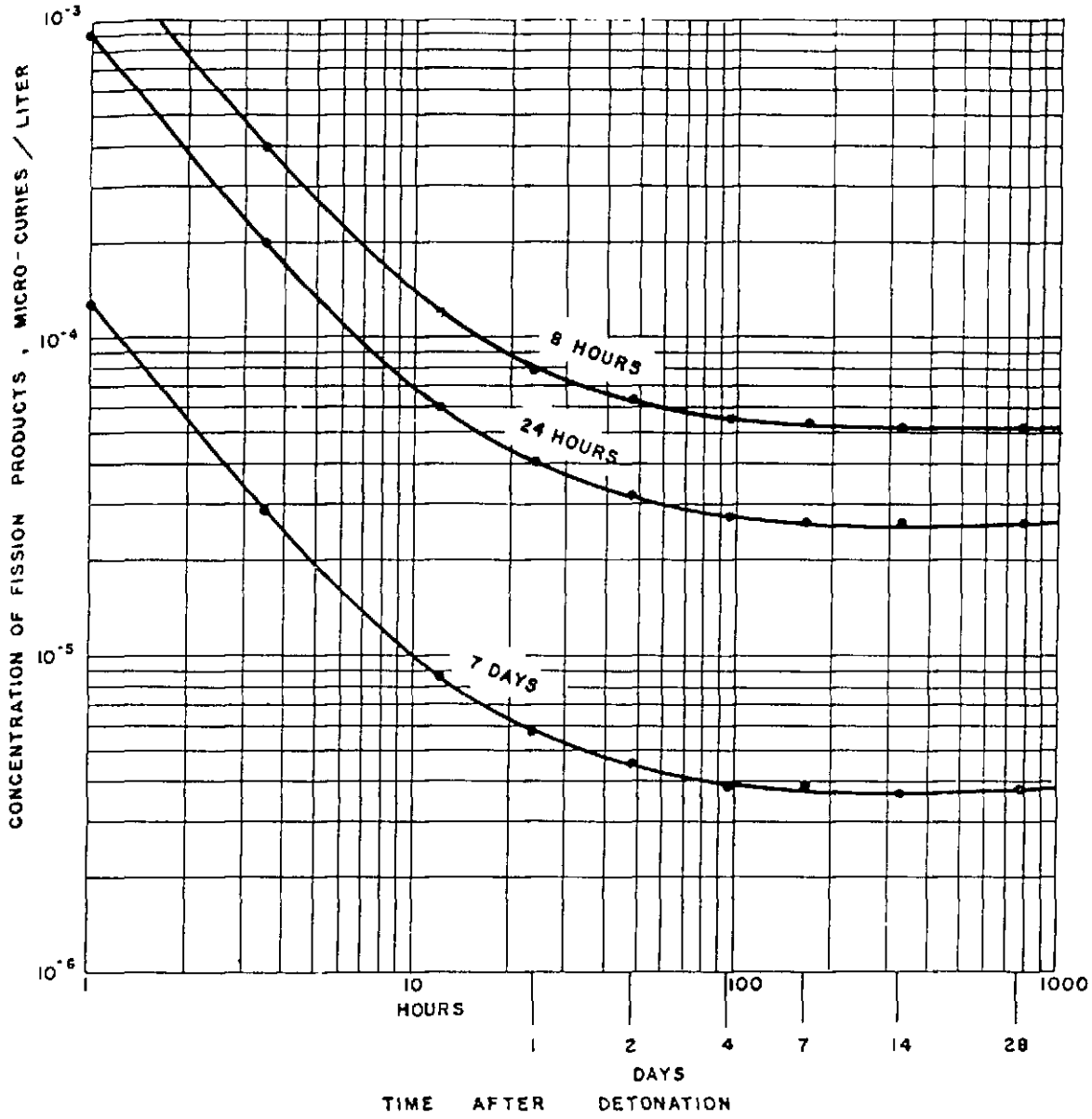


Fig. A.3 Maximum Permissible Concentrations of Fission Products in Air - 1 hr to 1000 hr (So that not more than 1 microcurie of equivalent Sr^{90} are retained in the body).

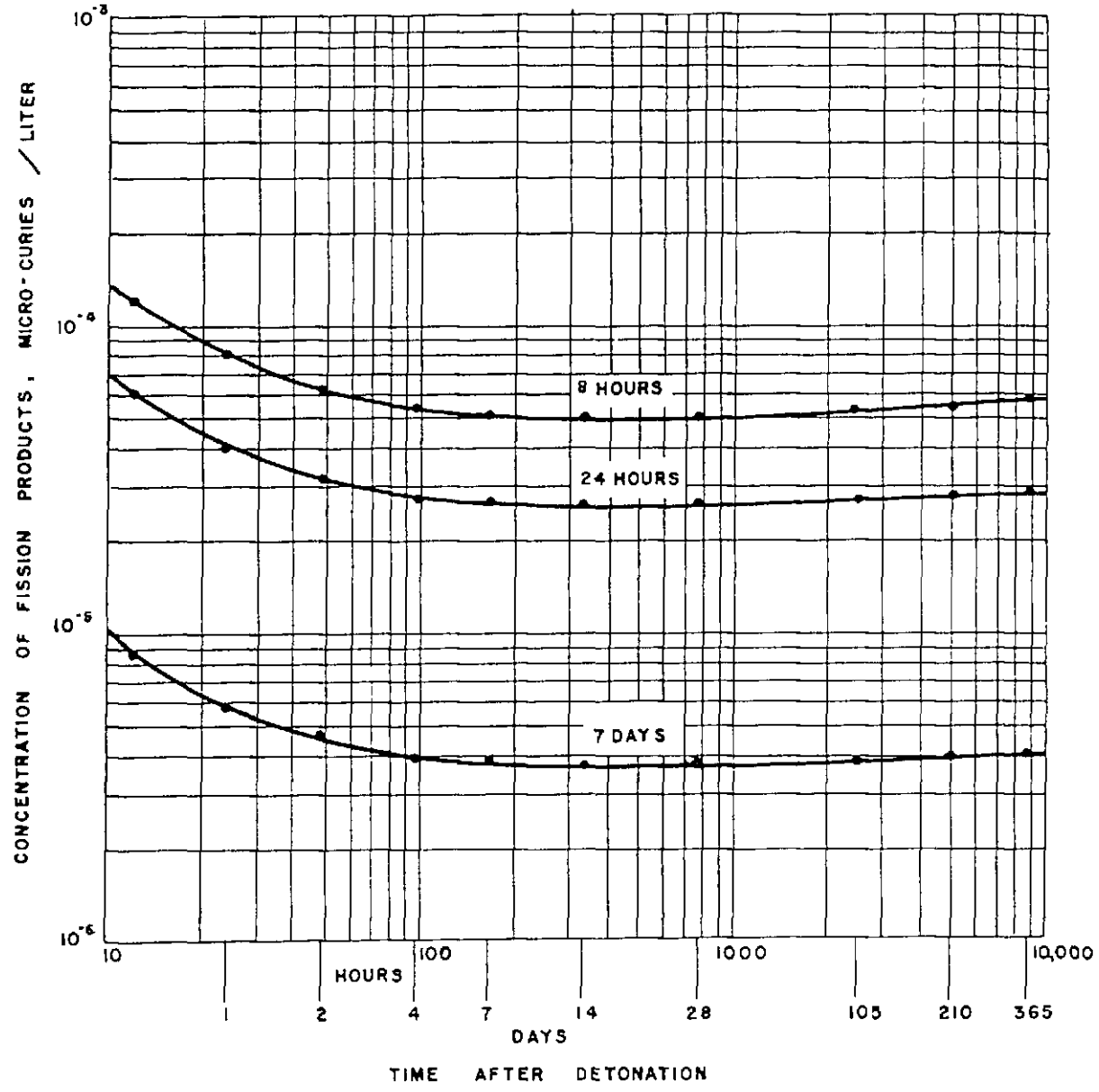


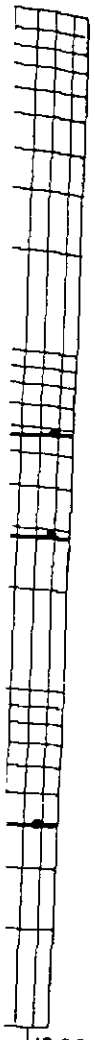
Fig. A.4 Maximum Permissible Concentrations of Fission Products in Air - 10 hr to 1 yr (So that not more than 1 microcurie of equivalent Sr^{90} are retained in the body).

was considered negligible in comparison). To be more explicit, Table A.3 shows for several times, the number of multiples of the maximum permissible quantity of iodine present when the maximum permissible concentration of Sr^{90} or one Sr equivalent is present. Thus, the total Sr^{90} equivalents was set high enough so that iodine could at no time present a hazard.

Finally, it will be noted in Fig. A.4 that a trend upward is indicated, commencing at 28 days after detonation. This trend is not unreasonable, if the 8-hr curve in Fig. A.4 is considered. It is noted from Hunter and Ballou activity plots that all the nuclides considered except Sr^{90}-Y^{90}, Pm^{147}, and Ce^{144}-Pr^{144} decay below 1 per cent of the total activity within 2 yr. Ce^{144}-Pr^{144} reach their peak activity at 1.5 yr, Pm^{147} at 5 yr. It follows therefore, that as the more hazardous nuclides decay, the 8-hr curve will tend to rise toward the figure given in Table A.1 for maximum permissible concentration in air of Sr^{90} for an 8-hr day.

A.5 SUMMARY

An attempt has been made to evaluate the inhalation hazard associated with fission products based on Sr^{90} equivalents of the various "bad actors". This has led to construction of graphs relating the maximum permissible concentration of fission product in air to time after detonation for exposure times of 8 hr, 24 hr, and 7 days.



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A.6 BIBLIOGRAPHY

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PROJECT 6.3-2
APPENDIX B

MAXIMUM ALLOWABLE CONCENTRATIONS OF FISSION PRODUCTS IN THE AIR AS A FUNCTION OF EXPOSURE TIME AND TIME AFTER DETONATION (Continued)

B.1 INTRODUCTION

Comment received by the author has indicated that the conditions assumed to exist in the preparation of reference (1) were unnecessarily pessimistic, and that much higher maximum permissible concentrations could be realized if less conservative, albeit equally supportable, assumptions were made. In addition it was indicated that the possibility of a plutonium hazard should not have been neglected. This paper then is an attempt to satisfy that criticism. In addition, the evaluation of the hazards of the various nuclides considered, relative to Sr^{90}, or their "Sr^{90} equivalents", (1) has been done in considerably more detail.

Although it has not been deemed necessary to repeat some of the detail in reference (1), it has been considered necessary to restate the basic assumptions, and the calculations presented so that to preserve continuity the reader would not be required to refer continually to reference (1).

B.2 ASSUMPTIONS

The assumptions, briefly stated, are as follows:

(a) The relative activities of fission products resulting from fast fission are essentially the same as those reported for slow neutron fission of U^{235} (2).

(b) The activity of Sr^{90} is constant from 1 hr to 1 yr after fast fission, and is in stable equilibrium with Y^{90} (2).

(c) The maximum permissible amount of Sr^{90} in the human body is 1 microcurie (3). This presupposes that 1 microcurie of Y^{90} is also present. Also, when 1 microcurie of Sr^{90} exists in the human body, no more than .3r/week will be delivered to the man site of deposition, which, in this instance, is the skeleton. This dose rate may not be exceeded since the factor of safety associated with it may be very low (4).

(d) For Sr^{90} in air, 25 per cent of the inhaled amount is absorbed, and 25 per cent of the absorbed amount is retained permanently (3).*

*Assumption modified from that in ref. (1).

[redacted]

All nuclides discussed in this paper are considered to behave similarly with the exception of I^{131} and Pu^{239}.

(e) All particles in a fission product mixture are considered to be of small enough size for them to reach the alveolar space and there to enter the blood stream, or the lymphatic system.

(f) The maximum permissible concentration in the body of a parent-daughter pair such as Zr^{95}-Cb^{95} is considered to be the same as that of the parent alone.**

(g) The standard man breathes 10 cu.m. or 10^4l., of air during an 8-hr working period, and 20 cu.m., or 2×10^4l., of air during a 24-hr day which includes an 8-hr working period (4).

(h) With the exception of iodine (3), the bone seeking elements are considered to be the most serious radioactive hazards.

(i) The maximum permissible amount of I^{131} in the body is .3 μc 100 per cent of airborne I^{131} can be inhaled and 20 per cent is retained permanently (3).

(j) For the purpose of this paper, the following assumptions are considered to apply to the fissionable material:

(aa) The fissionable material is Pu^{239}.

(bb) Fission efficiency is one per cent.

(cc) The unfissioned Pu^{239} is uniformly mixed with the fission products.

(dd) 100 per cent of the unfissioned Pu^{239} in the air may be inhaled.

(ee) 100 per cent of the inhaled Pu^{239} is absorbed and retained permanently (3).

(ff) U^{235} is not considered a radioactive hazard at all (

B.3 CALCULATIONS

The foregoing assumptions comprised all those necessary to compute the relative hazards of the fission products to Sr^{90}.

**Except for Sr^{90}-Y^{90}.

First Step

The concentrations of Sr^{90} in the air necessary to cause the absorption and retention of 1 microcurie were calculated (see Table B.1) from the following formula:

$$X = Z/Y \times 1/.25 \times 1/.25$$

Where X = Conc. of Sr^{90} in μc/l of air,

Y = Liters of inhaled air, and

Z = 1 μc of Sr^{90}, the maximum permissible concentration of Sr^{90} in the body.

TABLE B.1

Concentrations in the Air Necessary for Retention in the Human Body of 1 Microcurie of Sr^{90} (or 2 microcuries of Sr^{90}-Y^{90}) Based on 100 per cent Inhalation, 25 per cent Absorption of the Material Inhaled, and 25 per cent Retention of the Absorbed Material.

Period of Exposure	Conc. of Sr^{90} in μc/l of air
8-hr work day	1.6×10^{-3}
24-hrs*	8×10^{-4}
7-days*	1.14×10^{-4}

Second Step

It was then possible to calculate the concentrations of fission products necessary to cause the retention of 1 microcurie of Sr^{90} during three exposure periods.

Sample Calculation

Hunter and Ballou (2) report the Sr^{90} activity as 4.35×10^{-5} per cent of the gross fission product beta activity at 1-hr after fission. From Table B.1 the Sr^{90} concentration in the air necessary to cause the absorption and retention of 1 μc by the end of an 8-hr work day is 1.6×10^{-3}

*Includes 8-hr work period for each 24-hr period.

μc/l. Therefore, the gross fission product activity required to provide such a concentration is found as follows:

$$1.6 \times 10^{-3}/4.35 \times 10^{-5} \times 100 = 3680 \ \mu c/l$$

In the light of the foregoing, Table B.2 is self-explanatory.

TABLE B.2

Maximum Permissible Fission Product Concentrations

1	2	3	4	5
Time after detonation	Sr^{90} Act. as % of total beta activity	Gross fission product beta activity in μc/l required to cause retention of 1 μc of Sr^{90} in the human body during the following exposure times		
(2)	(2)	8-hr work day	24-hrs [a]	7 days [a]
1 hr	4.35×10^{-5}	3680.	1840.	262.
3.5 hrs	1.82×10^{-4}	880	440	62.8
12 hrs	6.56×10^{-4}	244	122	17.4
24 hrs	1.55×10^{-3}	103	51.5	7.35
2 days	3.86×10^{-3}	41.5	20.7	2.96
4 days	8.8×10^{-3}	18.2	9.1	1.30
7 days	1.52×10^{-2}	10.5	5.25	.75
14 days	2.96×10^{-2}	5.4	2.7	.39
28 days	5.95×10^{-2}	2.69	1.35	.193
105 days	2.67×10^{-1}	.60	.30	.043
210 days	7.3×10^{-1}	.22	.11	.0157
1 yr	1.96	.082	.041	.00585

[a] Each 24-hr period includes an 8-hr working period.

[redacted]

Third Step

Having calculated the gross fission product beta activity necessary to cause the retention of 1 μc of Sr^{90} during three periods of exposure at various times after detonation, the corresponding activities of the nuclides considered hazardous (see Table B.3) were determined (2). Each of these nuclides was considered to have an associated hazard which, for equal activities, is certain multiples of Sr^{90} hazard, determined on the basis of maximum permissible concentrations. This number was then multiplied by the ratio of the activity of the nuclide to the activity of Sr^{90} present in the fission product mixture. The resulting figure was called the "Sr^{90} equivalent".

Sample Calculation

At 1-hr the Sr^{90} activity is 4.35×10^{-5} per cent of the gross fission product beta activity, and the total beta activity of Zr^{95}-Cb^{95} = 6×10^{-3} per cent of the gross fission product beta activity.

$$6. \times 10^{-3}/4.35 \times 10^{-5} = 137$$

Now the maximum permissible concentration or Sr^{90} in the body is 1 μc, and that of the Zr^{95}-Cb^{95} pair, 3 μc (4). The toxicity of Zr^{95}-Cb^{95} to Sr^{90} is therefore 1/.3. Consequently, there exist 137 x 1.0/.3 = 460 "Sr^{90} equivalents" of Zr^{95}-Cb^{95} at 1 hr. Table B.3 was constructed in this way.

One might inquire at this point about the effect of the presence of Y^{90} which is in stable equilibrium with Sr^{90}. If the Y^{90} activity is considered as essentially that of Sr^{90}, then the Sr^{90} activity is effectively doubled, and the relative activity of Zr^{95}-Cb^{95} is halved. But the maximum permissible concentration of Y^{90} must be added to that of Sr^{90}, which is then effectively doubled. Thus while the activity of Zr^{95}-Cb^{95} relative to Sr^{90} (plus the Y^{90} increment) is halved, its relative toxicity is doubled. The net result is that there is no difference if Zr^{95}-Cb^{95} is compared to Sr^{90} or to Sr^{90}-Y^{90}.

Fourth Step

The "Sr^{90} equivalents" in Table B.3 were divided into the corresponding figures in columns 3, 4, 5 of Table B.2. The results were tabulated in Table B.4. Thus Table B.4 is a compilation of the fission product concentrations necessary to cause the retention of 1 microcurie of "equivalent Sr^{90}" activity at various times after an atomic bomb detonation for three different times of exposure.

Fifth Step

Now finally it is necessary to calculate the effect of Pu^{239}. The calculations of Hunter and Ballou (2) are based on the simultaneous

TABLE B.3

Analysis Sheet

Listed below are those fission products which constitute internal hazards. Their beta activities and "Sr equivalents" are given for various times.

1	2	3		4		5		6		7		8		9		10		11		12		13		14	
Nuclides	Max. Per. con. in the body in micro-curies	1 hr		3.5 hrs		12 hrs		24 hrs		2 days		4 days		7 days		14 days		28 days		105 days		210 days		1 yr	
		Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents	Per cent of total activity	Sr^{90} equiva-lents
(6)	(3)(4)(6)	(2)		(2)		(2)		(2)		(2)		(2)		(2)		(2)		(2)		(2)		(2)		(2)	
I^{131} (a)	0.3	0.023	5650	0.101	6000	0.41	6650	0.98	6700	2.29	6350	4.56	5550	6.18	4300	6.68	2600	3.97	705	.0022	0	0	0	0	0
Sr^{90}-Y^{90} (b)	2.0	4.35×10^{-5}	2	1.8×10^{-4}	2	6.5×10^{-4}	2	1.05×10^{-3}	2	1.8×10^{-3}	2	8.8×10^{-3}	2	1.52×10^{-2}	2	2.9×10^{-2}	2	5.95×10^{-2}	2	0.267	2	0.73	2	1.96	2
Sr^{89}	2.0	0.006	69	0.029	80	0.1	76	0.24	77	0.587	76	1.30	74	2.13	70	3.83	62	6.39	54	10.9	20	7.31	5	2.60	0.7
Ba^{140}-La^{140}	5.8	0.037	147	0.16	153	0.66	173	1.73	192	4.71	210	11.4	224	18.4	208	25.3	147	23.8	69	1.66	1.0	0.002	0	0	0
I^{91}	0.3	0.177	13600	1.35	25000	2.9	11800	3.20	6900	1.9	1640	1.53	580	2.34	520	4.25	244	7.20	404	12.9	160	9.75	44.5	4.00	6.8
Zr^{95}-Cb^{95}	0.3	0.006	460	0.031	570	0.11	505	0.27	580	0.68	587	1.47	556	2.54	555	5.5	326	11.5	645	35.0	437	38.8	177	32.1	54.6
Ce^{144}-Pr^{144}	0.3	0.0027	207	0.012	220	0.043	218	0.10	215	0.25	216	0.58	220	0.99	207	1.88	108	3.68	206	13.7	171	28.7	131	32.3	89
Ce^{143}-Pr^{143}	0.3	0.27	20700	1.20	22000	3.65	18500	7.5	16100	11.6	10000	12.7	4820	11.3	2480	11.5	660	11.5	645	1.08	13	0	0	0	0
Nd^{147}-Pm^{147}	0.3	0.018	1380	0.074	1350	2.7	13500	6.3	13600	1.43	1240	2.86	1080	4.10	900	5.15	294	4.19	234	1.02	13	2.28	20.0	5.66	9.6
Total Sr^{90} equivalents			36565		49375		47774		37666		13971		7556		4942		1845		2259		817		369.5		145.7

(a) The figures given under the column "Sr^{90} equivalents" for I^{131} indicate only the multiples of maximum permissible I^{131} activity when the maximum permissible concentration of Sr^{90} is present. These figures are not included in the totals.

(b) Only Sr^{90} activity is given in this row. The total activity of Sr^{90}-Y^{90} may be considered as being double the figures given.

TABLE B.4

Maximum Permissible Fission Product Concentrations

Time after detonation	Sr^{90} Equivalents*	Gross fission product beta activity in μc/l required to cause retention of 1 μc of "equivalent" Sr^{90} in the body during the following exposure times**		
		8-hr work day	24-hrs***	7 days***
1 hr	36,600	.10	.05	.0072
3.5 hrs	49,400	.0178	.0089	.00127
12 hrs	47,800	.0051	.00255	.00036
24 hrs	29,400	.0035	.00175	.00025
2 days	16,000	.0026	.0013	.000185
4 days	9,100	.0020	.001	.00014
7 days	6,550	.0016	.0008	.00011
14 days	4,320	.00125	.00062	.000098
28 days	2,690	.00100	.00050	.000072
105 days	835	.00072	.00036	.000052
210 days	366	.00060	.00030	.000043
1 yr	150	.000540	.00026	.000037

*These figures were taken from the last row of figures in Table B.3, and were adjusted to give a smooth set of curves.

**The figures in these three columns were determined by dividing the figures in the corresponding columns of Table B.2, by the corresponding number of "Sr^{90} equivalents".

***Includes an 8-hr work day each 24 hrs.

NOTE: The author has felt free to adjust the figures in this table to get a smooth curve, since it is reasonable to expect that 100 per cent inhalation will not occur,

[illegible]

of Pu^{239} remains unchanged. A brief glance then at table B.? shows that the Pu^{239} hazard becomes significant at 105 days after fission.

B.4 DISCUSSION

As was stressed in the preceding report (1), this study is largerly qualitative, and consequently subject to modification. It should be noted that this report has served simply to reduce the estimated percentage of absorbed and retained Sr^{90} for a given concentration in the air, to refine the calculations of the percent activity of fission products at various times, and to consider the plutonium hazard.

*For Iodine it is 20 per cent (3).

[redacted]

[redacted]

I^{131} was included as a check in the discussion because of its low maximum permissible concentration, and its high percentage of absorption of the body (3).

It will be noted that the contribution of Pu^{239} to the internal hazard has not been considered in the construction of figures B.1 and B.2. It must be emphasized therefore that after 1 year the curves will tend to approach asymptotes which are about 100 times the magnitude of the figures in Table B.1. This is obvious since Pu^{239} is about 50 times as hazardous as Sr^{90} for equal activities.

In closing, some of the questionable aspects of this report will be noted briefly. Particle size distribution (5), as an added safety factor, has only been considered roughly, and then only to smooth the curves. Neither the chemical nor physical state has been mentioned. Of course, the factor which may serve to upset all these calculations may be the dose received from material accumulated in the lungs. The computation of such a dose is beyond the scope of this paper.

B.5 SUMMARY

A graph of the maximum permissible concentrations of fission products as a function of time of exposure and time after detonation has been prepared using Sr^{90} as a basis for comparison for several fission products and plutonium.

[redacted]

PROJECT 6.3-2

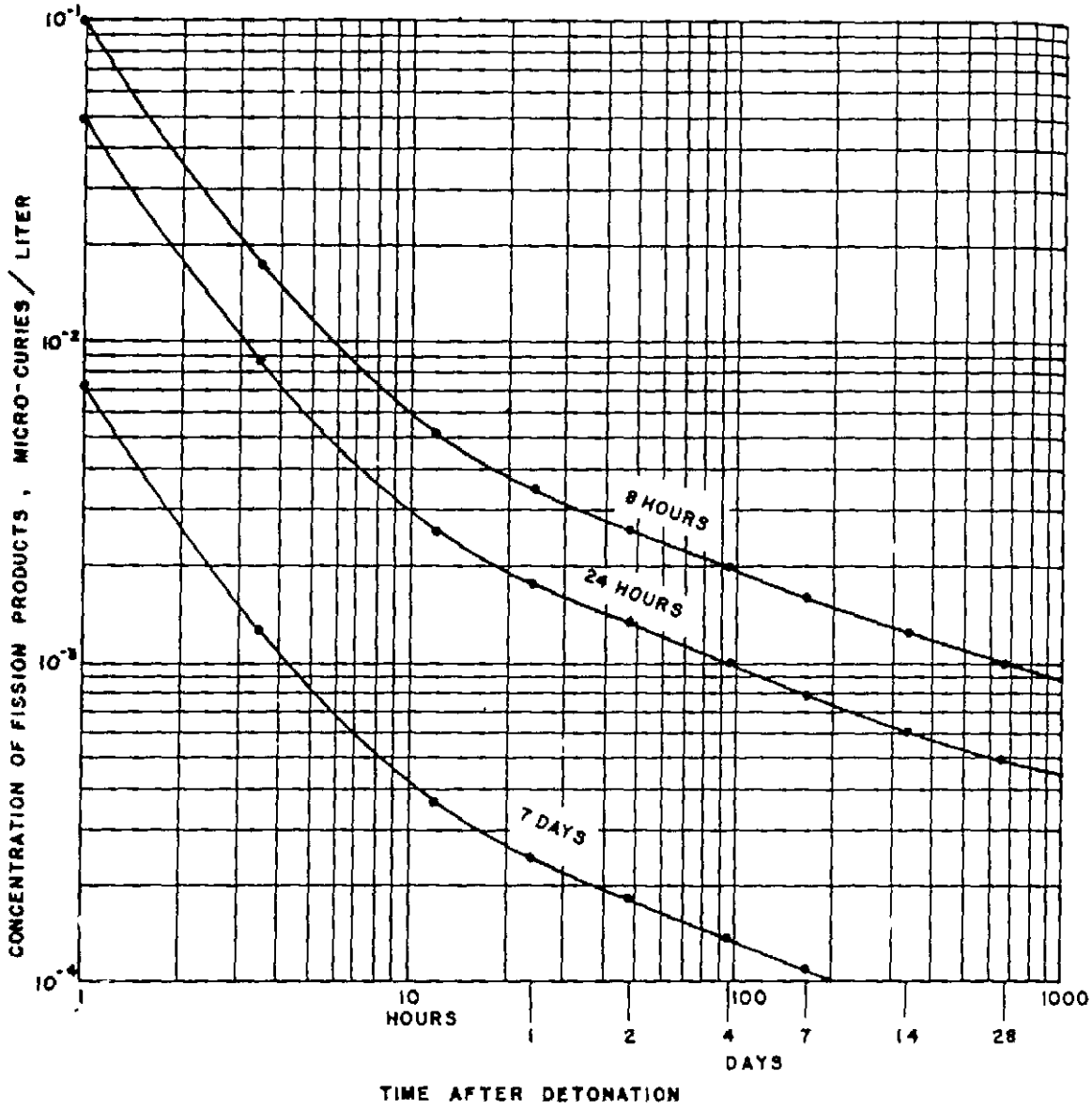


Fig. B.1 Maximum Permissible Concentrations of Fission Products in Air - 1 hr to 1000 hr (So that not more than 1 microcurie of equivalent Sr^{90} is retained in the body).

[redacted]

[redacted]

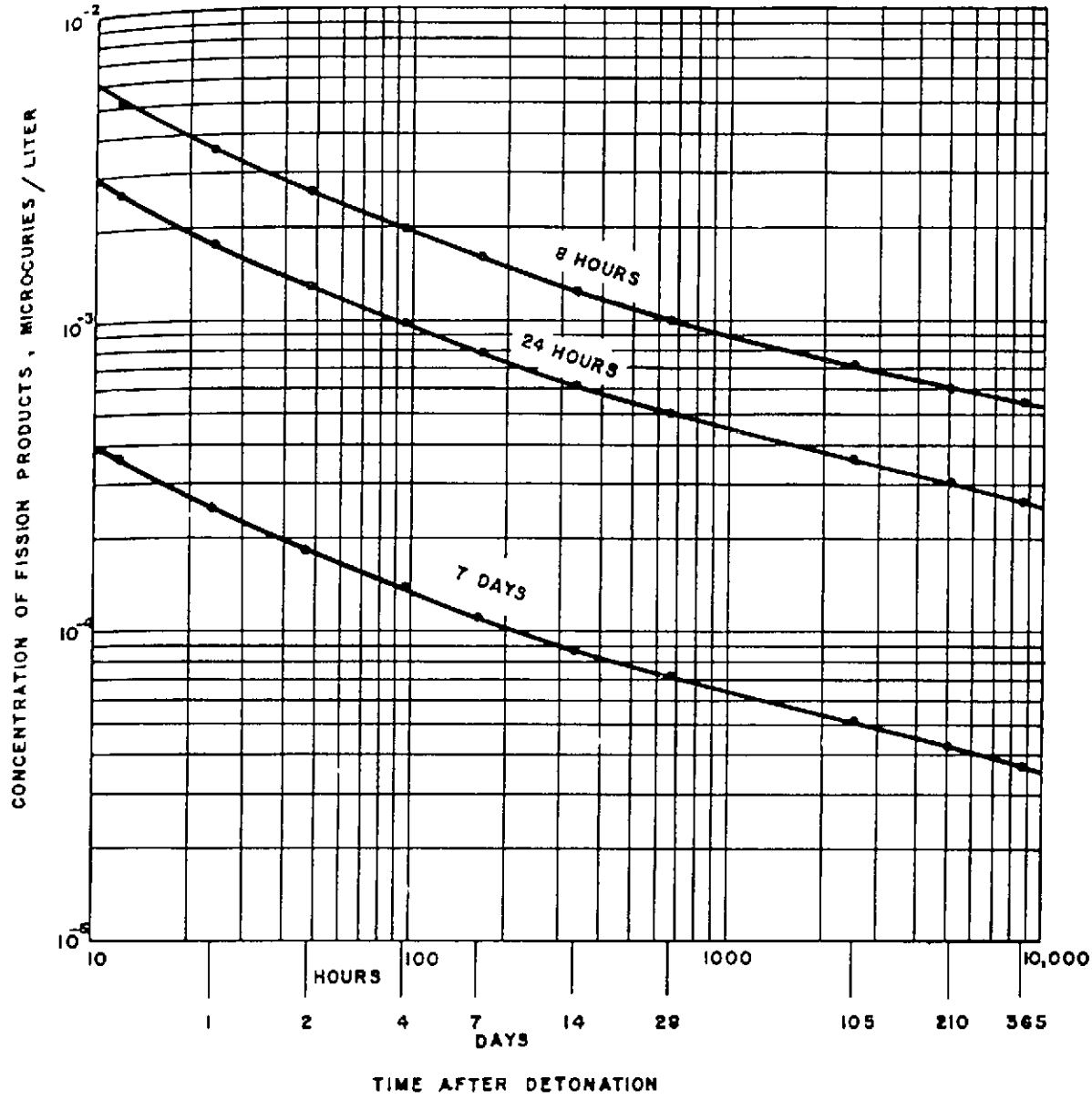


Fig. B.2 Maximum Permissible Concentrations of Fission Products in Air - 10 hr to 1 yr (So that not more than 1 microcurie of equivalent Sr^{90} is retained in the body).

B.5 BIBLIOGRAPHY

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